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Optimizing access and configuration of trauma centre care in New South Wales

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ABSTRACT

Introduction: Getting the right patient, to the right place, at the right time is dependent on a multitude of modifiable and non-modifiable factors. One potentially modifiable factor is the number and location of trauma centres (TC). Overabundance of TC dilutes volumes and could be associated with worse outcomes. We describe a methodology that evaluates trauma system reconfiguration without reductions in potential access to care. We used the mature trauma system of New South Wales (NSW) as a model given the perceived overabundance of urban major trauma centres (MTC).
Methods: We first evaluated potential access to TC care via ground and air transport through the use of geographic information systems (GIS) network analysis. Potential access was defined as the proportion of the population living within 60-min transport time from a potential scene of injury to a TC by ground or rotary-wing aircraft. Sensitivity analyses were carried out in order to account for potential pre-hospital interventions and/or transport delays; travel times of 15-, 30-, 45-, 60-, and 90-min were also analyzed. We then evaluated if the current configuration of the system (number of urban MTS in the Sydney basin) could be optimized without reductions in potential access to care using two GIS methodologies: location-allocation and individual removal of MTC.
Results: 86% of the NSW population has potential access to a TC within 60 min ground travel time; potential access improves to 99% with rotary-wing transport. The 1% of the population without potential TC access lives in 48% of the land area (>384,000km2). Utilizing two different methodologies we identified that there was no change in potential access by ground transport after removing 1 or 2 MTC in the Sydney basin at the 30-, 45-, and 60-min transport times. However, 0.02% and 0.5% of the population would not have potential access to MTC care at 15 min after removing one and two MTC respectively.
Discussion: Redistribution of the number of MTC in the Sydney basin could be achieved without a significant impact on potential access to care. Our approach can be utilized as an initial tool to evaluate a trauma system where overabundance of coverage is present.

Introduction

Traumatic injury continues to be a public health emergency with over five million annual deaths worldwide [1]. Injury continues to be the leading cause of death in those under 45 years of age both globally and in Australia [1,2]. The development of pre-hospital capabilities (e.g. triage guidelines, rapid transport, retrieval physician deployment) coupled with the establishment of centres that have both the structures and processes required to manage severely injured patients, has led to reductions in morbidity and mortality after injury [3–5].

The mantra of getting the right patient, to the right place, at the right time is dependent on a multitude of modifiable and non-modifiable factors. Non-modifiable factors include but are not limited to rural/remote locations of injury, population density,

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inclement weather limiting use of transportation resources, road usage patterns of congestion, and prolonged extrication times. Modifiable factors include pre-hospital triage guidelines, availability of rotary-wing transport from the scene of injury, training and staffing of pre-hospital personnel, and inter-facility transfer agreements. One potentially modifiable factor, commonly understudied, is the number and location of trauma centres.

The monetary and political costs associated with the modification of each of these factors are not necessarily correlated with reciprocal improvements in under/over triage. Furthermore, each trauma system will have inherent challenges based on geography, population density and distribution, injury patterns, pre-hospital capabilities, and trauma centre number and location. In order to optimize the performance of the trauma system, a comprehensive analysis of all these factors must be undertaken. We describe a methodology that evaluates potential trauma system reconfiguration which can be easily adapted to other geographic locations with nascent or mature trauma systems. In an era of ever expanding number of trauma centres, the evaluation of trauma system configuration is essential.

We used the mature trauma system of the state of New South Wales, Australia, as a model given the strong pre-hospital capabilities, inclusive nature, rural challenges in coverage, and the perceived overabundance of urban trauma centres in the Sydney basin. Six of the seven major trauma centres (MTC) in New South Wales are located in the Sydney basin. We first evaluated potential access to trauma centre care for the region as a whole through the use of geographic information systems (GIS) network analysis. Once potential access had been established, we evaluated if the current configuration of the system (i.e. number of MTC for the Sydney basin) could be optimized without reductions in potential access to care.

Methods

Setting

New South Wales (NSW) is Australia's most populous state with over 7.8 million inhabitants with the inclusion of the Australian Capital Territory (ACT). The state is over 800,000 km^2 with an overall population density of 9.7 people/km^2; however, approximately 5 million people live in the greater Sydney area adjacent to the state's south east coast (population density of 406.7/km^2).

Trauma care in Australia is publically funded. The NSW and the ACT inclusive trauma system consists of seven Major Trauma Centres (MTC, six of which are located in the Sydney basin, and ten Regional Trauma Centres (RTC) [6]. MTC are largely equivalent to level I trauma centres as defined by the American College of Surgeons (ACS) [7]. All MTC are located in major metropolitan areas. RTC are located predominantly in major regional towns and within the Sydney basin. A RTC provides initial assessment, stabilization, and initiates transfer to MTC if required. Each RTC has a designated MTC for referral and support. RTC can provide definitive care to patients with minor to moderate injuries as well as definitive care to a limited number of severely injured patients in collaboration with the MTC. For the most part, an RTC is equivalent to a level III trauma centre as defined by the ACS [7].

There is one government ambulance system (NSW Ambulance) for the entire state of NSW with standardized trauma triage and management protocols. NSW ambulance acts as a central dispatch system for both ground and air transport. State-wide pre-hospital triage criteria state that patients meeting major trauma criteria should be transported to the highest level Trauma Centre located within a 60 min travel time from the scene, even if this means bypassing closer hospitals and/or an RTC. When transport times of 60 min are not feasible, transport to MTC/RTC or non-trauma hospitals are directed under the instruction of a physician at the Aeromedical Control Centre [8]. The Rotary-wing aircraft in service in NSW are Agusta Westland 139 long-nose aircraft which are search and rescue (SAR), winch capable, and carry a crew of four (pilot, air crewman, retrieval physician and critical care paramedic). Rotary-wing aircraft operate out of seven bases 24 h a day.

Data sources

Location of MTC and RTC were obtained from the New South Wales Institute of Trauma and Injury Management 2015 report and were geocoded in ArcGIS [9]. Location of aeromedical bases was obtained by one of the authors (BB). Street network data for NSW were obtained from Open Street Map, which provides information on the street type and speed limits [10]. Street network data were verified from other road networks obtained from the open data portal from the NSW government [11]. Population data were obtained from the 2016 Australian Census at the Statistical Area 1 level. There are 17,981 Statistical Area level 1 s in NSW which have population counts between 200–800 people [12].

Potential access to trauma centre care

Potential access to trauma centre care was defined as the proportion of the population living within a pre-specified transport time from a potential scene of injury to a trauma centre (i.e. either MTC or RTC) by ground or rotary-wing aircraft [13,14]. Our main outcome measure was 60-min travel time as specified in the NSW pre-hospital triage criteria [8]. Fixed-wing aircraft transport was not included as our main outcome of interest was direct transport from the scene of injury to a trauma centre. Sensitivity analyses were carried out in order to account for potential pre-hospital interventions (e.g. extrication, intubation) and/or transport delays (e.g. traffic, weather); therefore, travel times of 30, 45, 60, and 90 min were analyzed.

This approach is dependent on the assumption that the location of residence can be used as a surrogate for the location of injury. Data from Ontario, Canada which has a population distribution and size that is similar to NSW, demonstrates that 88% of injuries occur within 16 km from location of residence (median 0.3, IQR 0–3.5 kilometres) [15]. These findings are concordant with analyses of pediatric injuries [16], adult pedestrian injuries [17], as well as motor vehicle collisions in England [18].

Geographic analysis

Potential access to trauma was measured in GIS for both rotary-wing (i.e. helicopter) and ground travel (i.e. ground ambulance). Statistical Area 1 (SA1) level polygons were converted to points at the centre of the polygon (i.e. population centroid points). SA1 polygons range in sizes depending on the population, the median size is 0.18 km^2 (IQR: 0.33 km^2).

Two approaches were undertaken for rotary wing-transport. First, we evaluated what proportion of the population lives within 30, 45, 60 and 90, and minutes transport time to a trauma centre as our main outcome measure. Next, in order to provide additional validity to our assumptions, we evaluated what proportion of the population lives within 1 h of one of the seven aeromedical rotary-wing bases in order to evaluate whether rotary-wing transport is even feasible for the entirety of the NSW population. Rotary-wing travel used straight line travel distances from the population centroid points to either aeromedical bases or trauma services in order to create access buffers for 30, 45, 60, and 90 min travel times based on a cruise speed of approximately 240 km/h. We identified that 99.4% (n = 7,819,677) of the population of NSW lives within 60 min flying time of one of the seven aeromedical bases (Fig. 1). For the rest of the analysis we

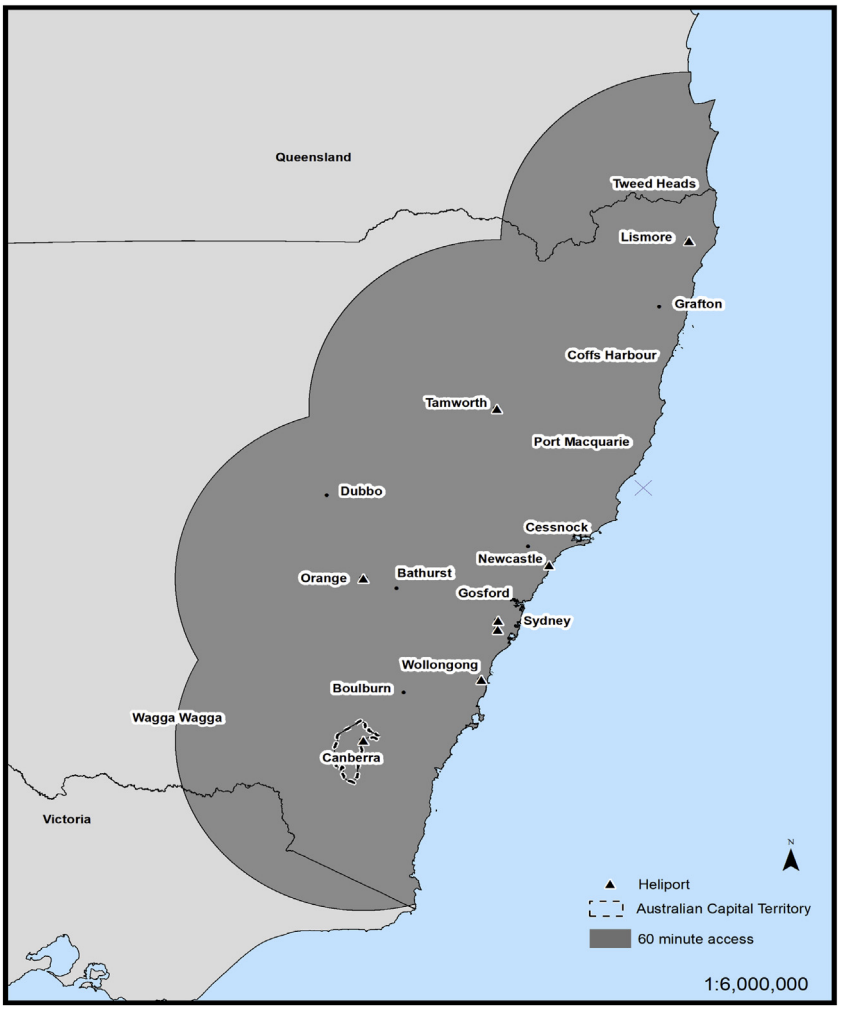

Fig. 1. Potential access from all rotary-wing bases within 60 min.

assumed that aeromedical coverage is ubiquitous in NSW given the current coverage and refueling capabilities.

Ground travel times were estimated by using the network analyst function in ArcGIS (10.4.1). A network dataset for NSW was compiled using the road network data, speed limits, and driving restrictions for one-way streets. Travel time was used as the impedance for all ground travel analyses. We elected to include speed limits and driving restrictions in order to provide a more conservative estimate of travel times as not all scene transports may require "lights and sirens". Service area network based polygons were compiled for 30, 45, 60, and 90 min travel times.

The number of people with potential access, based on either the rotary-wing travel buffers and/or ground transportation service areas, was then estimated. If the population centroid point was within the buffer/service area, residents of that area were assumed to have potential access. A sample of travel routes were validated using travel times reported in Google Maps to ensure proper estimation with the network dataset. Subgroup analyses were also carried out for either only ground or rotary-wing transport and for either transport to only MTC or RTC.

Trauma system optimization

In an effort to maximize trauma system efficiency and ensure potential access to trauma centre care, we undertook two approaches to evaluate the impact of potentially reducing the number of trauma services in NSW. Given the geographic location and lack of overlap in coverage across RTC, removal of any RTC would have reduced the proportion of the population with access to trauma services. For this reason we focused on evaluating MTC in the Sydney basin where there is a perceived overabundance of MTC and subsequent significant overlap in coverage.

Firstly, the location-allocation function within ArcGIS was used to evaluate the impact of removing one or more MTC. The location-allocation tool uses demand points (i.e. population) and facilities (i.e. MTC) to identify ideal locations for ensuring maximum potential access, but also minimizing the number of facilities. Our real-world approach only analyzes existing trauma centres and does not evaluate ideal potential locations of new trauma centres as this is only useful in nascent trauma systems. Secondly, we evaluated the impact of removing each MTC individually. Given that air coverage was considered ubiquitous, optimization analyses were limited to ground transportation only. Data are presented in both tabular and graphical formats.

Results

According to the 2016 Australian Census, the combined population of NSW and the ACT was 7,864,701 people; overall, 86.1% of the population lives within a 60 min ground transport time to either an MTC or RTC. Two thirds of the population lives within 30-min ground transport time to a MTC. Once rotary-wing transport is included, 99.2% of the population lives within 60 min driving or flying time to either an MTC or RTC (Table 1).

Table 1
Potential access to trauma care by ground transport.

	30-min	45-min	60-min	90-min
Overall	6,151,578 (78)	6,540,315 (83)	6,772,728 (86)	7,164,323 (91)
MTS	5,133,606 (65)	5,535,944 (70)	5,939,949 (76)	6,158,890 (78)
RTS	2,871,610 (36)	5,243,182 (67)	6,117,327 (78)	6,615,686 (84)

All data presented as n (%) unless otherwise specified. MTS: Major Trauma Service. RTS: Regional Trauma Service.

Although 0.8% of the population (n = 66,950) does not have potential access by either ground or rotary-wing transport at a 60-min travel time, this 0.8% of the population lives in 48% of the land area on NSW (over 384,000 km^2) (Fig. 2). Potential access increases to 99.5% when 90-min ground or rotary-wing transport was considered (Fig. 2).

Trauma system optimization of the Sydney basin

The location-allocation function identified two MTC which could be removed without any changes to potential access at 30-, 45-, and 60-min ground travel times. These two MTC were located in the central business district of Sydney.

We also evaluated the impact on potential access to care of removing 1, 2, and 3 MTC from the Sydney basin (Fig. 3). There was no change in potential access to MTC care by ground transport after removing 1 or 2 centres at the 30, 45, and 60 min mark. However, 0.02% and 0.5% of the population would not have potential access to MTC at 15 min after removing one and two MTC respectively. Removing three MTC would lead to a decrease in potential access at all time-intervals, over 500,000 population with no coverage at 15 min transport time and over 30,000 with no coverage at 60 min transport time.

The impact of different system configurations would not be uniform across the system. As evidenced in Table 2, only two MTC would have significant increases to the number of people served in the 5 and 4 MTC configurations as these represent populations that had overlapping areas of coverage. However, all MTC would see significant increases in coverage with a three MTS configuration.

Discussion

Trauma centre care is a key component of trauma systems [4]. Historically, in the design of trauma systems, designation of trauma centres has been based on existing hospitals within a region. In particular, no inclusive trauma system has been built from the "ground-up" (i.e. specific trauma centres constructed in pre-planned locations in order to maximize coverage). The New South Wales trauma system does not differ in this respect. Existing hospitals were designated as Major or Regional Trauma Centres based on resources and geographic health areas within the state [19]. This led to the perceived overabundance of major trauma centres in the Sydney basin. This is reflected in the most recent report of the New South Wales Institute of Trauma and Injury Management which states that yearly volume of major trauma admissions varied from a low of 214 to a high of 615 patients across MTC in 2017. The two MTC located in the central business district of Sydney, which are in close geographic proximity to each other, had the lowest volumes [20]. Other major metropolitan areas around

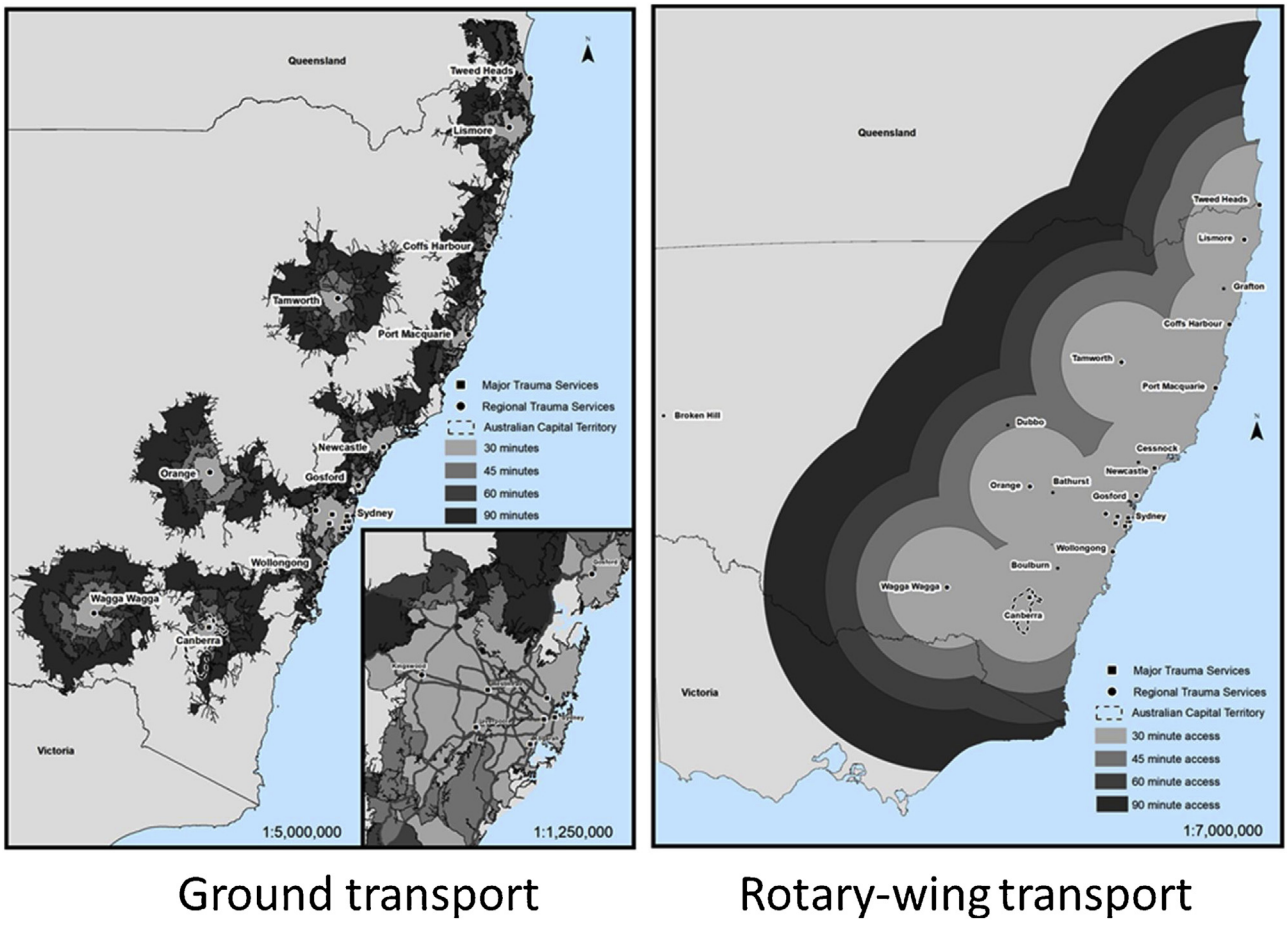

Fig. 2. Potential access to trauma centre care in New South Wales, 2016 Potential access to either MTS or RTS by either 30-, 45-, 60-, or 90-min of ground or rotary-wing transport.

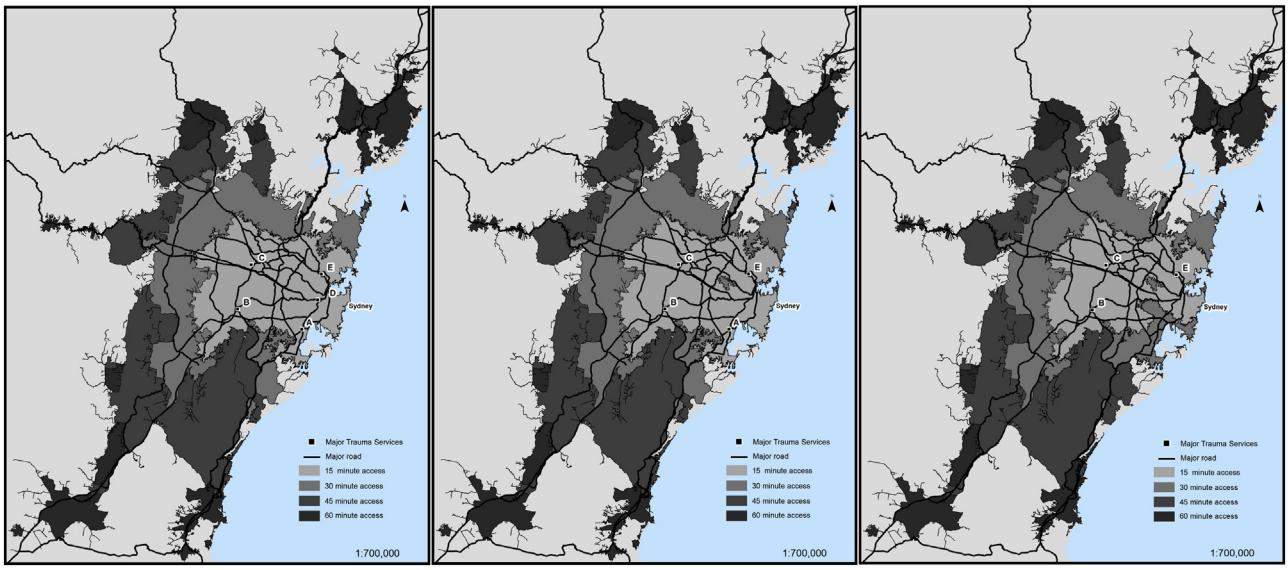

Fig. 3. Change in potential access to Major Trauma Services with different system configurations Evaluation of different system configurations and potential access with 5, 4, or 3 major trauma services in the Sydney basin.

Table 2
Change in potential access to MTS in the Sydney basin with different system configurations.

Hospital	15 min		30 min		45 min		60 min	
	Coverage	Change	Coverage	Change	Coverage	Change	Coverage	Change
A	565,290		619,576		699,752		841,208	
B	651,057		801,425		834,118		862,360	
C	938,018		1,234,678		1,277,361		1,300,318	
D	446,409		446,409		446,409		446,409	
E	595,125		784,476		807,641		1,002,097	
F	409,553		409,553		409,553		409,553	
Total	3,605,452		4,296,117		4,474,834		4,861,945	
A	597,600	+32,310	651,886	+32,310	732,062	+32,310	873,518	+32,310
B	651,057	0	801,425	0	834,118	0	862,360	0
C	938,018	0	1,234,678	0	1,277,361	0	1,300,318	0
D	822,790	+376,381	823,639	+377,230	823,639	+377,230	823,639	+377,230
E	595,138	+13	784,489	+13	807,654	+13	1,002,110	+13
Total	3,604,603	−849	4,296,117	0	4,474,834	0	4,861,945	0
A	887,000	+321,710	941,617	+322,041	1,021,793	+322,041	1,163,249	+322,041
B	651,057	0	801,425	0	834,118	0	862,360	0
C	989,957	+51,939	1,292,843	+58,165	1,335,526	+58,165	1,358,483	+58,165
E	1,058,846	+463,721	1,260,232	+475,756	1,283,397	+475,756	1,477,853	+475,756
Total	3,586,860	−18,592	4,296,117	0	4,474,834	0	4,861,945	0
B	846,811	+195,754	1,392,980	+591,555	1,468,648	+634,530	1,652,758	+790,398
C	1,017,207	+79,189	1,331,326	+96,648	1,374,009	+96,648	1,396,966	+96,648
E	1,234,764	+639,639	1,562,814	+778,338	1,585,979	+778,338	1,780,435	+778,338
Total	3,098,782	−506,670	4,287,120	−8,997	4,428,636	−46,198	4,830,159	−31,786

Depicts change in potential access at different transport times for system configurations of 6, 5, 4, and 3 MTS in the Sydney basin. Change denotes the difference in each MTS' population coverage between the 6 MTS configuration and the alternate configurations.

the world, such as Boston and New York City, have similar configurations with multiple major trauma services located within the same geographic area with overlapping areas of coverage. This overabundance of centres dilutes volumes and could be associated with worse outcomes [21]. Understanding potential access to care based on existing trauma system infrastructure is the first step towards optimizing trauma system efficiency.

This study has three key findings. Firstly, 86% of the population has potential access to either a major trauma service or regional trauma service within 60 min ground travel time. Potential access is lower when analyzing potential access to MTC (76%) or RTC (78%) specifically. However, rates observed in New South Wales are still higher compared to published rates of potential access to trauma centre care at 60 min ground travel times across comparable regions, specifically Ontario, Canada (60%) [13]. When considering rotary-wing transport, 99% of the state's population could be transported to a trauma service within 60 min. Similarly, these potential access rates are higher than those reported in Ontario, Canada (84%) [13] and the continental United States (84%) [14]. Higher rates of potential access observed in New South Wales are likely secondary to higher population density around trauma services and significant investments in air transportation assets.

Secondly, redistribution of the number of major trauma centres in the Sydney basin of New South Wales could be achieved without a significant impact on potential access to care. Utilizing two different methodologies we identified that there was no change in potential access to MTC care by ground transport after removing 1 or 2 MTC at the 30, 45, and 60 min mark. The majority of the state's

population resides within the Sydney metropolitan area, resulting in the concentration of tertiary academic hospitals and subsequent designation of multiple major trauma centres with overlapping areas of coverage. Consolidating the major trauma caseload across fewer centres addresses the volume-outcome relationship [21], and allows for potential concentration/reallocation of resources across the entire health system.

Thirdly, we have described a simple approach that can be easily adapted to other mature trauma systems where overabundance of coverage is present. The potential application of GIS in trauma research was initially explored by Branas and Schuurman describing the core methodologies for evaluating potential access to emergency care [14,22–29]. The utility of GIS in designing trauma systems from the "ground up" was demonstrated in the recently implemented Scottish trauma system. [30]. This methodology assisted the appropriate determination of major trauma centres based on population access and caseload [31]. Horst et al examined the optimal placement of Level I/II trauma centres within Pennsylvania and concluded that reconfiguration of the existing network, by redistribution of the existing 27 trauma centres, resulted in a 3.3–6.2% increase in the number of trauma cases that would have access to a trauma centre within 60 min road transport time [32]. Our approach acknowledges that a complete redesign is not a realistic option for mature systems. On the other hand, we describe a simple technique that evaluates whether a reduction in the number of trauma centres can be achieved without changes to potential access to care.

Our study has several limitations. Variables pre-arrival for road and rotary wing transport were not considered. However the T1 (trauma triage/bypass) protocol only stipulates the maximum transport time from the scene of injury, not including the pre-arrival time. The use of census-population data as a surrogate for place of injury is an assumption and is not a direct measure of realized access to care. However, given the lack of population-based injury data available for NSW, the use of a proxy was required. Both potential and realized access to care, are key trauma system performance indicators that should be considered when evaluating the performance of a trauma system. [13] Redistribution of major trauma services based on potential access alone, does not account for capacity at the major trauma services that would absorb the potential additional patients, or the increased resources required. In addition, capacity may be overwhelmed in a mass-casualty event, if a reduction in number of MTC is considered without appropriate redistribution of resources through the entire system. The overabundance of centres in Boston has been cited as one of the keys to the success of the response to the marathon bombings. No cost-analysis has been performed to examine the effect of redistribution of resources.

Conclusions

The NSW state trauma system has above average potential access to trauma centre care, challenges remain in rural areas. Redistribution of the number of urban TCs in the Sydney basin could be achieved without a significant impact on potential access to care. Our approach can be utilized as an initial tool to evaluate a trauma system where overabundance of coverage is present.

Conflicts of interest

The authors have no conflicts of interest to declare.

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